Deep-Sea Mining: Can It Contribute to Sustainable Development?

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1. Introduction

Sustainable development is a kind of "development that meets the needs of the present without compromising on the ability of future generations to meet their own needs" (Brundtland 1987, para. 27). It aims at balancing economic development with human well-being and environmental conservation, taking into account concerns of inter- and intragenerational equity. The need to divert from a business-as-usual development path to a more sustainable one was re-emphasized by the international community in 2015, when all of the United Nations' member states adopted the 2030 Agenda for Sustainable Development (A/RES/70/1). The 2030 Agenda presents "a plan of action for people, planet and prosperity" (A/RES/70/1, preamble) and brings together the 2000 Millennium Development Goals (MDGs) and the climate and environment agenda rooted in the 1992 Earth Summit (Rio de Janeiro, Brazil) (BMU 2015). At the center of the 2030 Agenda are 17 interlinked sustainable development goals (SDGs) with 169 associated targets, which reflect the 2030 Agenda's objectives to "end poverty and hunger everywhere; to combat inequalities; to protect human rights and promote gender equality and the empowerment of women and girls; and to ensure the lasting protection of the planet and its natural resources", as well as the creation of "conditions for sustainable, inclusive and sustained economic growth, shared prosperity and decent work for all, taking into account different levels of national development and capacities" (A/RES/70/1, page 3).

Whether mining is compatible with the concept of sustainable development is debatable. On the one hand, mineral resources serve as important raw materials used for the manufacture of a myriad of goods, including, inter alia, construction materials and electronic devices (UNDP and UN Environment 2018). Furthermore, the export of mineral raw materials makes up a large share of the national economies of many countries. On the other hand, mining entails the exploitation of a finite resource which is often associated with substantial environmental destruction. Furthermore, once depleted, the resource will no longer be available for future generations, as mineral deposits take millions of years to form. Due to declining ore grades, it is likely that terrestrial mines will in the future be forced to expand more rapidly both laterally and vertically to keep the production constant. Furthermore, it is expected that mines will move into more remote terrains, which taken altogether will likely intensify social and environmental pressures (Calvo et al. 2016).

Deep-sea mining, which describes the recovery of marine minerals from the deep seabed, may in the future contribute to meeting the metal demand of the growing world population (Hein et al. 2013). The idea of deep-sea mining first emerged in the 1960s, when the economic potential of marine mineral resources was widely recognized (Mero 1965; Sparenberg 2019). At that time, the interest in deep-sea mining was purely economic and geostrategic, as deep-sea mining was seen as a means to generate revenue and to decrease the dependency on foreign metal exports (Sparenberg 2019; Koschinsky et al. 2018). For a long time, the deep-sea mining narrative has, in this regard, followed the assumption that marine mineral resources are of greater value if they are exploited and converted into revenue (Christiansen et al. 2019). This is underpinned by the claim that deep-sea mining could provide the metals needed for the transition to a low-carbon economy (Paulinkas et al. 2020; Hein et al. 2013). Moreover, studies claim that deep-sea mining may, in fact, be more environmentally friendly than terrestrial mining (Paulinkas et al. 2020; Batker and Schmidt 2015; Hein and Koschinsky 2014; Koschinsky et al. 2018). This rather positive outlook on deep-sea mining is, however, increasingly challenged, as concerns about the potential large-scale and long-term environmental impacts and the potential implications for human and ecosystem well-being are raised (Weaver and Billet 2019). Furthermore, it has been questioned whether a comparison of terrestrial and deep-sea mining is even warranted, given that there is no indication that deep-sea mining will eventually replace terrestrial mining. Instead, it is more likely that both will be carried out in parallel, ultimately intensifying environmental and social conflicts even further (Christiansen et al. 2019).

With commercial deep-sea mining on the horizon, it becomes increasingly important to explore if and how deep-sea mining can contribute to sustainable development. This requires a thorough assessment of environmental, economic and social concerns (Figure 1). Following this introduction, this chapter will present the three different types of marine mineral deposits under consideration to be mined, including envisioned mining concepts, and quickly explain the legal context of deep-sea mining. Subsequently, the chapter will outline environmental, economic and social considerations and conclude with a section on implications for sustainable development.

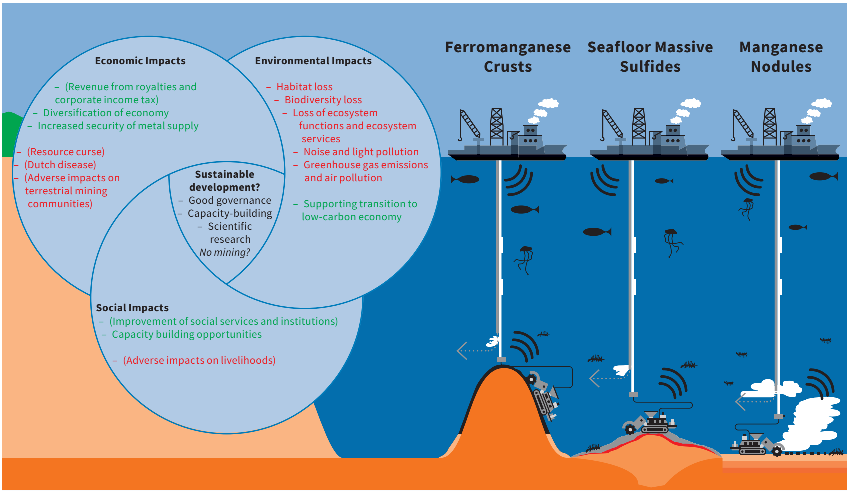

Figure 1. Overview of marine mineral deposits, mining techniques, and impacts. Positive and negative impacts are shown in green and red, respectively. Impacts in parentheses indicate potential impacts, which can be good or bad depending on external factors, such as the availability of effective policies or capacity-building initiatives. Impacts without parentheses are certain. Source: Figure by author; modeled after (Aldred 2019).

2. Types of Marine Mineral Deposits

Manganese nodules (here forth simply referred to as nodules) are small, potato-shaped mineral concretions, which mainly consist of concentric intergrown layers of iron and manganese oxides, but also contain significant quantities of various metals, including nickel, copper, cobalt, molybdenum, zinc, platinum, tellurium, and rare earth elements (Hein and Koschinsky 2014). They form by the precipitation of metals from seawater or sediment pore water and occur nearly everywhere on the world's oceans, but are especially abundant in the Clarion-Clipperton-Zone (CCZ), the Peru Basin, near the Cook Islands (all located in the Pacific Ocean), and the Central Indian Ocean Basin (Hein et al. 2013; Petersen et al. 2016). Most nodule mining concepts envision mining operations to consist of one or more remotely operated vehicles, which will collect nodules at the seafloor. From there, the nodules will be pumped through a riser pipe and deposited onboard a production support vessel at the surface. Onboard, the nodules will be washed, partially dried and stored until they are collected by a transport vessel and brought to land, where they will be metallurgically processed. The wastewater sediment mixture will be returned to the water column (Atmanand and Ramadass 2017; Blue Mining 2014; Hong et al. 2010; Ramboll IMS & HWWI 2016). It has been suggested that this should happen at near-seafloor depth to avoid the contamination of pelagic ecosystems (Drazen et al. 2020).

Ferromanganese crusts (here forth simply referred to as crusts) form through the precipitation of metals on the sediment-free summits, platforms, slopes and saddles of seamounts in water depth between 400 and 7000 m over the course of millions of years (Hein and Koschinsky 2014). They consist of strongly intergrown sub-crystalline iron and manganese oxide layers of up to 25 cm thickness and contain economically interesting quantities of other metals, including nickel, copper, cobalt, molybdenum, zirconium, niobium and rare earth elements and reach a known maximum thickness of about 25 cm (Halbach et al. 1982; Hein et al. 1992; Lusty et al. 2018). It is believed that there are thousands of seamounts located across the world's oceans, but the Prime Crust Zone (PCZ), which stretches from the Mariana Trench to the Hawaiian Islands, is of particular interest because of its high abundance of crusts with highly valuable metal contents (Wessel et al. 2010; Lusty et al. 2018; Hein and Koschinsky 2014). Due to their firm attachment to the underlying rock, the mining of crusts is considered challenging (Lusty et al. 2018; Koschinsky et al. 2018). In August 2020, the Japan Oil, Gas, and Mineral National Corporation (JOGMEC) announced that it conducted the world's first successful crust-mining test, during which they excavated 649 kg of crusts from the seafloor off the Japanese coast, using a crust-excavating testing machine developed by JOGMEC itself (JOGMEC 2020).

Seafloor massive sulfide (SMS) deposits form in hydrothermally active areas through the precipitation of minerals, when hot metal-rich hydrothermal fluids cool or get in contact with cold ambient seawater (Hannington et al. 2005). They consist mainly of metal–sulfur compounds and contain significant amounts of iron, copper, zinc, silver, and gold, as well as smaller quantities of rare earth elements (Monecke et al. 2014). SMS deposits are located in geologically active areas such as mid-ocean ridges, and in volcanic arc and back arc basins, and at intraplate volcanoes (Petersen et al. 2016). Based on plume studies and deposit occurrence models, Hannington et al. (2011) estimated that there are between 500 and 5000 vent fields with associated mineral deposits. Hydrothermal vent fields are considered active, while the venting of hydrothermal fluids is ongoing, inactive and eventually extinct when it ceases. Vents located on slow-spreading ridges (e.g., Atlantic Ocean) can last for hundreds of thousands of years whereas those located on fast-spreading riches (e.g., East Pacific Rise) often rise and fall over decades (Copley et al. 2016).

Deep-sea mining of seafloor massive sulfide deposits will likely concentrate on inactive vent sites, which have accumulated over a longer time than active vent sites (German et al. 2016; Van Dover et al. 2018). Furthermore, active venting of hot hydrothermal fluids may pose a significant threat to mining equipment (SPC 2013c). Mining concepts currently envision the combined use of different seafloor vehicles (bulk cutter, auxiliary cutter and collector), which will cut and collect the ore at the seafloor. From there, it will be pumped to the seafloor, cleaned from sediment onboard a mining vessel and then transported to shore for further metallurgical processing (SPC 2013c). More recently, the use of vertical cutter systems has been suggested (Spagnoli et al. 2016).

3. Deep-Sea Mining in Areas within and Beyond the Limits of National Jurisdiction

The responsibility of regulating the exploration and exploitation of marine mineral deposits in territorial waters, exclusive economic zones (EEZs) and the continental shelf zones lies with the respective coastal states, who are obligated by the United Nations Convention on the Law of the Sea (UNCLOS) to adopt appropriate regulations that are "no less effective than international rules, standards and recommended practices and procedures" (UNCLOS, Article 208 (3), see Section 4.3 below for information on environmental obligations of coastal states). Deep-sea mining in areas beyond national jurisdiction is primarily regulated by Part XI of UNCLOS (the Area) and the corresponding 1994 Agreement relating to the implementation of Part XI of UNCLOS (1994 IA). The international seabed (termed the Area by UNCLOS) and its resources constitute the Common Heritage of Mankind (CHM) (UNCLOS, Article 136), which means that the resources of the Area are vested in mankind as a whole (UNCLOS, Article 137 (1)), effectively prohibiting states from claiming, acquiring, or exercising sovereign rights over them (UNCLOS, Article 137 (3)). Instead, the resources of the Area are managed by the International Seabed Authority (ISA), which has been established by UNCLOS (153 (1)), and is to act on behalf of mankind as a whole (UNCLOS, 137 (2)).

The CHM principle has been established to ensure that the benefits from exploiting the resources of the Area are shared by all countries "irrespective of the geographic location of States, whether coastal or land-locked, and taking into particular consideration the interests and needs of developing States" (UNCLOS, Article 140). As such, its objective is to prevent a situation in which the benefits obtained from seabed mining can only be enjoyed by industrialized countries, which have the financial capacity and technical skill to carry out such an expensive and risky endeavor (Jaeckel et al. 2016). Key elements of the CHM principle include (1) the exclusive use of the international seabed for peaceful purposes (UNCLOS, Article 141), (2) the principle of non-appropriation (UNCLOS Article 137 (1)), (3) the reservation of mineable areas for developing states in the Area, (4) the equitable sharing of any monetary and non-monetary benefits (UNCLOS, Article 140(2)) and (5) the protection and preservation of the marine environment for the benefit of current and future generations (UNCLOS, Article 145). To this end, the ISA's main tasks include the development of a regulatory and administrative structure that allows the sharing of monetary and non-monetary benefits and the development of stringent environmental regulation, which ensures the protection and preservation of the marine environment from the impacts of deep-sea mining, taking into account concerns of intergenerational and intragenerational equity (Frakes 2003; Jaeckel et al. 2016; Bourrel et al. 2018; Joyner 1986; Kiss 1985).

Deep-sea mining in the Area can either be carried out by the Enterprise (the ISA's would-be mining entity responsible for mining, transporting, processing and marketing marine minerals recovered from the Area) and, in association with the ISA, by member states of UNCLOS, state and private enterprises, natural or juridical persons who have the nationality of a member state and who are sponsored by such a state (UNCLOS Article 139). The sponsoring state is required to ensure that the contractor (i.e., the entity entering into exploration or mining contracts with the ISA) complies with the terms of its contract and with the relevant provisions of international law. In this regard, the sponsoring state has an obligation of due diligence in setting and enforcing its laws and regulations, meaning that it has to adopt, implement and enforce appropriate rules and regulations (ITLOS 2011), which, according to Lily (2018), may include the provision of "institutional capabilities such as an identified regulatory body, with monitoring and enforcement functions and access to appropriate personnel, equipment and other technical capacity to implement them"(p. 2). Wherever sponsoring states have implemented appropriate measures, they cannot be held liable for a contractor's misconduct (ITLOS 2011).

As of December 2020, the ISA has entered into 30 exploration contracts, eighteen of which are for nodules, five for crusts and seven for SMS deposits (ISA 2020).

4. Environmental Considerations

4.1. Environmental Impacts of Deep-Sea Mining

4.1.1. Biological Impacts

Manganese nodules are loosely placed in and on top of the sediment of the abyssal plains of the oceans in an environment, which is characterized by high pressure, low temperature and very slow dynamics of (bio)geochemical processes. The nodules serve as a habitat for a variety of sessile and mobile faunal taxa (e.g., bacteria, nematodes, harpacticoid copepods, polychaeta, isopod crustaceans, holothurians, fish, corals, bryozoans, xenophyophores, and sponges), which typically feed on detritus and fecal pellets produced by zooplankton sinking down from the sea surface (marine snow) (SPC 2013b; Vanreusel et al. 2016; Weaver and Billet 2019; Amon et al. 2016). Collector vehicles moving over the seafloor will not only destroy the nodules and with it the habitat for organisms using the nodules as hard substrate, but will also stir up the sediment, effectively threatening bottom-dwelling and filter-feeding organisms (Weaver and Billet 2019; Koschinsky et al. 2018). In addition to this, the re-deposition of the suspended sediment is also expected to adversely affect these organisms, as this would likely happen at a much higher rate than natural sedimentation (Weaver and Billet 2019).

Ferromanganese crusts provide solid substrate for sessile filter feeding taxa (e.g., corals, sponges) and a variety of mobile taxa, including echinoderms, squids, and foraminifera (Mullingneaux 1987; Weaver and Billet 2019; Clark et al. 2010). The distribution of species and the composition of communities vary depending on factors like water depth, current flow and type of substrate (Clark et al. 2010). Research has indicated that the seamounts host considerably more biomass than the slopes of continental margins at the same depth (Rowden et al. 2010). The removal of the crusts would inevitably lead to the vast destruction of large areas of habitat. Furthermore, the mining of crusts could produce particle plumes, including resuspended sediment and abraded crust particles. However, as seamounts will only accumulate sediment on plateaus and in crevices, the size and distribution of the particle plume will likely be much smaller than the plume generated by nodule mining (SPC 2013b; Koschinsky et al. 2018; Hein and Koschinsky 2014).

SMS deposits, specifically active hydrothermal vent fields, provide unique habitats for a variety of highly specialized organisms (e.g., shrimp, tube worms and bacteria) (SPC 2013c). Many of these species are endemic to individual vents and rely on a well-functioning symbiotic relationship with certain chemoautotrophic species (SPC 2013b; Van Dover et al. 2018). Vent communities also show a zonation, meaning that the different organisms occur at different distances to the vent (Rogers et al. 2012). The impacts of SMS mining will likely be site-specific due to variations in local abiotic conditions, including substrate type, water depth, temperature, salinity and particulate organic matter supply from the surface (Boschen et al. 2016). Overall, the area affected by mining will be smaller than the area influenced by nodule or crust mining, as SMS mines would mostly extent into the sub-seafloor (SPC 2013c; Weaver and Billet 2019). However, due to the uniqueness of individual active vent habitats, the mining of active vents would risk destroying rare types of habitat. Furthermore, due to the smaller size of the deposits, more vent sites would likely have to be mined. However, it is more likely that inactive vent sites would be preferentially mined in the future, as they may provide larger ore deposits and would be technically easier to mine than active vent sites. While here fauna can be expected to be more similar to the ambient deep-sea fauna of the region, as the typical vent fauna can only survive at actively venting sites, the paucity of ecological studies at inactive SMS deposits makes clear assessments of a potential environmental impact of mining difficult (Van Dover 2019). Like for active SMS, the affected area of mining would be much smaller than the affected area of nodule or crust mining.

4.1.2. Geochemical Impacts

Deep-sea mining can also cause geochemical changes by altering the chemical equilibrium of the sediment-water interface as a consequence of the excavation of marine mineral resources and the removal of surface sediment. In the case of nodule mining, the extent of the release of toxic metals from seawater and sediment pore water is believed to be small, unless mining causes particularly deep disturbances. Strong interferences could, however, occur in areas where the oxygen penetration depth in the sediment is very low. Recent studies suggest, however, that oxygen reaches depths of more than 1.5 m throughout the CCZ (Mewes et al. 2014; Volz et al. 2020). In the Peru Basin, where nodules are also highly abundant, the oxygen penetration depth is only between 10–15 cm (Haeckel et al. 2001; Paul et al. 2018). Crust mining is not expected to cause a significant release of toxic metals, as the crusts typically form under fully oxic conditions. However, if crusts on shallow seamounts close to the oxygen minimum zone would be mined, a partial redissolution of manganese oxide from crust particles and release of trace metals within the oxygen minimum zone could take place (Koschinsky et al. 2003). The mining of SMS deposits may have a substantial geochemical impact because of the high oxidation potential and reduced state of the sulfide minerals (Van Dover et al. 2020). Research has shown that even species inhabiting active vent sites, which are characterized by a comparatively high concentration of metals in the surrounding water, may be negatively affected by elevated metal concentrations due to mining (e.g., Hauton et al. 2017). Although many vent species may be more adapted to changing environmental conditions and appear to have developed mitigation strategies against metal toxicity (vent mussels, for example, store immobile metal compounds in their tissue, Koschinsky 2016), it is unclear to which limits these adaptation strategies would protect these organisms against metal release from SMS mining.

4.1.3. Particle Plumes

The operation of the collector vehicles at the seafloor and the discharge of excess sediment and water from the mining vessel will create metal-rich particle plumes close to the seafloor and in the water column, which may negatively affect benthic and pelagic ecosystems and may extend far beyond the mine site (SPC 2013a, 2013b, 2013c). Whereas early research mostly relied on hydrodynamic models to anticipate the dispersion of the plume (Jankowski and Zielke 2001; Rolinski et al. 2001), more recent experiments show aggregation effects, indicating that previous research may have overestimated the range of dispersion of the plume (Gillard et al. 2019). Nevertheless, fine particles can be transported over long distances and potentially negatively affect marine organisms (Weaver et al. 2018). The mining of the slopes of seamounts and active vent sites is not expected to produce large particle plumes, as these are generally not covered with a thick sediment layer. Guyots and crevices of seamounts, as well as inactive vent sites can, however, accumulate sediment. Similarly, inactive hydrothermal vent sites may also be covered by several centimeters of sediment, which may be dispersed during mining and the discharge of excess water and sediment from the mining vessel (Weaver and Billet 2019; Van Dover et al. 2020).

4.1.4. Noise and Light Pollution

Exposure to noise and vibrations resulting from mining operations can compromise the ability of marine organisms to communicate and to detect prey. As noise travels well underwater, noise pollution could affect an area much greater than the mine site (Weaver et al. 2018). Noise impacts may be particularly severe in water depth in the upper 2000 m of the water column, where it may negatively affect marine mammals (Weaver and Billet 2019). Similarly, lights attached to mining equipment could disturb species that are accustomed to living in a dark environment (Popper et al. 2003; Weaver et al. 2018; Weaver and Billet 2019). Furthermore, artificial light may conceal bioluminescence, which may compromise the ability of marine organisms to navigate, mate, detect food and defend against predation. Near the vessels, artificial light may also attract organisms and disrupt their movement and above the sea surface. Furthermore, birds may be adversely affected by the lights illuminating the working decks of the mining vessels (Weaver and Billet 2019).

4.1.5. Greenhouse Gas Emissions and Air Pollution

The combustion of fuel oil onboard the mining and transport vessels will cause the release of greenhouse gases (i.e., CO_2, CH_4, N_2O) and other air pollutants (e.g., CO, SO_x, NO_x, NMVOCs, PM) (IMO 2015). These emissions will contribute to global warming, acidification, and the formation of photochemical ozone (Huijbregts et al. 2016). Thus far, the impacts to air directly resulting from deep-sea mining have received little attention in research. They should, however, be considered in a holistic assessment of the environmental impacts caused by deep-sea mining, especially in the context of climate change mitigation, and incorporated in regulatory frameworks (Heinrich et al. 2020).

4.1.6. Ecosystem Services

The impacts caused by deep-sea mining may also affect ecosystem functions and services (Le et al. 2017; Orcutt et al. 2020; Thornborough et al. 2019). Ecosystem functions of marine ecosystems include element and nutrient cycling, the provision of breeding grounds, nursery habitats and refugia, bioturbation, dispersal and connectivity, as well as primary and secondary productivity, metabolic activity and respiration (Le et al. 2017). Ecosystem services describe the benefits humans obtain from well-functioning ecosystems and are commonly subdivided into provisioning services, regulating services, supporting services and cultural services (MEA 2005). Provisioning services obtained from marine ecosystems, for example, include fish, shellfish, biomaterials, pharmaceuticals and industrial agents. Regulating services, for example, include carbon sequestration, the control of pests and populations, and the storage, burial, transformation and detoxification of waste material and pollutants. Cultural services include aesthetic and spiritual value, educational services and the notion of ocean stewardship. Supporting services include the ecosystem functions listed above (Le et al. 2017; Armstrong et al. 2012). Biodiversity is considered to be of particular importance in supporting ecosystem functions, although the relationship between biodiversity and ecosystem services has not yet been fully understood (Balvanera et al. 2014; Bennett et al. 2015). How and to what extent deep-sea mining will affect ecosystem functions and ecosystem services is uncertain but may be substantial. It should, therefore, be considered in the development of regulatory frameworks and management practices (Thornborough et al. 2019; Le et al. 2017).

4.2. The Mitigation Hierarchy

The mitigation hierarchy provides a systematic approach for reacting to the environmental impacts of an activity. Its main objective is to avoid net loss of biodiversity and, wherever possible, to achieve net gain. The mitigation hierarchy requires the consideration of four elements in a strict hierarchical order: (1) avoid, (2) minimize, (3) restore, (4) compensate/offset (Billet et al. 2019). Although originally developed for application in a terrestrial setting, it is now increasingly applied to coastal and marine environments, including the deep-sea. The first objective of the mitigation hierarchy is to avoid deep-sea mining altogether by reducing the overall demand for metals through recycling, substituting non-renewable with renewable materials and changing consumer behavior, although it is unclear whether this would be sufficient to meet the increasing demand of the growing world population (Billet et al. 2019; Rühlemann et al. 2019). If the complete avoidance of deep-sea mining is, indeed, impossible, then measures should be undertaken to at least protect certain areas from mining through the establishment of marine protected areas in which no mining can take place. An important measure in this regard is the establishment of regional-scale environmental management plans (REMPs), which is supposed to help maintain regional biodiversity, ecosystem structures and ecosystem function and to preserve typical regional ecosystems (Cuvelier et al. 2018; Niner et al. 2018; Jacob et al. 2016). According to Jones et al. (2019), REMPs for deep-sea mining may include "an assessment of the probability, duration, frequency and reversibility of environmental impacts, the cumulative and transboundary impacts, the magnitude and spatial extent of the effects, the value and vulnerability of the area likely to be affected including those with protection status and the extent of uncertainty in any of the above" (p. 175). The ISA has, until now, only adopted a REMP for the nodule fields of the CCZ, whose central component is a network of nine Areas of Particular Environmental Interests (ISBA/24/C/3). The APEIs cover an area of 400 km × 400 km, representing the nine sub-regions of the CCZ. The guiding principles of the CCZ REMP are listed as (1) the CHM, (2) the precautionary approach, (3) the protection and preservation of the marine environment, (4) the requirement to conduct environmental impact assessments, (5) the conservation and sustainable use of biodiversity and (6) transparency. The establishment of representative APEIs is complicated by the persisting lack of knowledge about species abundances and community composition in the deep sea. There is, however, a clear call for the establishment of further REMPS (including APEIs) in the Area, including prospective sites for the mining of crusts and SMS deposits. The selection of APEIs should be guided and by a comprehensive set of environmental criteria and objectives.

Moreover, Tunnicliffe et al. (2020) point out that “clearly identified targets using well-defined and standardized performance indicators [are needed] to evaluate progress (or lack thereof) towards achieving desired outcomes” (p. 3). Due to the uniqueness of SMS habitats, finding representative sites for the placement of APEIs will, however, be challenging (Koschinsky et al. 2018). Within areas of national jurisdiction, the Pacific Community established the Regional Environmental Management Framework for Deep Sea Minerals Exploration and Exploitation in cooperation with the EU (Swaddling 2016).

The second objective of the mitigation hierarchy is to minimize adverse environmental impacts as much as possible via technological means. While habitat destruction by seafloor vehicles is inevitable in a deep-sea mining context, it may be possible to reduce the impact of the particle plume. Niner et al. (2018), for example, suggest the use of shrouds on seafloor vehicles to limit the production and spreading of fine particles and Cuvelier et al. (2018) mention the possibility to increase flocculation to encourage a faster settling of the plume. Furthermore, the use of alternative energy sources (e.g., liquefied natural gas (LNG)) and the increase of the energy efficiency of the ship engines could limit the release of greenhouse gases and air pollutants (Heinrich et al. 2020). The third objective of the mitigation hierarchy is to restore ecosystem function and services after destruction. While this is common practice in terrestrial mining, the restoration of deep-sea ecosystems is extremely difficult due to the large scale of the affected areas, persisting knowledge gaps, and limited economic feasibility (Van Dover et al. 2014; Niner et al. 2018; Billet et al. 2019). The compensation/offsetting of biodiversity loss can be considered as a last option to prevent a net loss of biodiversity. This can be achieved by protecting or restoring similar habitats to those mined (like for like), or to create new biodiversity of a different kind in different types of environments (out of kind). It may, furthermore, be possible to compensate in an entirely different manner, for example, through investing in capacity-building initiatives. However, Niner et al. (2018) point out that out of kind compensation can neither negate biodiversity loss nor compensate for lost ecosystem functions and should, therefore, not be considered true offsets.

4.3. Environmental Regulation

4.3.1. National Jurisdiction

In areas within national jurisdiction, UNCLOS obligates coastal states to ensure the protection and preservation of the marine environment (UNCLOS, Articles 192 and 193). In this regard, UNCLOS requires states to attempt “as far as practicable, directly or through the competent international organization to observe, measure, evaluate and analyze by recognized scientific methods, the risks or effects of pollution of the marine environment" resulting from activities "which they permit or in which they engage" (UNCLOS, Article 204). Wherever states suspect "substantial pollution [or] significant harmful changes to the marine environment", they are required to "as far as practicable, assess the potential effects of such activities on the marine environment and shall communicate reports of the results of such assessments" (UNCLOS, Article 206) to the competent international organizations (UNCOS, Article 205). With respect to deep-sea mining, coastal states are obligated by UNCLOS to "adopt laws and regulations to prevent, reduce and control pollution of the marine environment arising from or in connection with seabed activities subject to their jurisdiction", as well as "other measures that may be necessary to prevent, reduce, and control such pollution" (UNCLOS, Article 208 (1) and (2)), further specifying that "such laws, regulations and measures shall be no less effective than international rules, standards and recommended practices and procedures" (UNCLOS, Article 208 (3)). In this regard, UNCLOS, article 194 (3c) obligates states to minimize "pollution from installations and devices used in exploration or exploitation of the natural resources of the seabed and subsoil" (UNCLOS, Article 194 (3c)). This also includes the obligation of states to prevent transboundary harm arising from activities conducted in areas under their jurisdiction (UNCLOS, Article 194 (2)).

Several states have already enacted specific deep-sea mining regulations or incorporated them within existing frameworks. Papua New Guinea, has, for example, incorporated provisions for deep-sea mining in its 1992 Mining Act. The Mining Act aims mainly to encourage mining and contains very little environmental provisions. These are included in the 2000 Environment Act, which, for example, requires the submission of environmental impact statements (EIS) (including monitoring, environmental management programs, collection of baseline data and remediation), and Environmental Inception Reports (§51(b)). Past experience with terrestrial mining operations, as well as the country's high level of poverty, civil conflict, inequality and poor rule of law gives rise to concern, however, with respect to the implementation and enforcement of the regulations (Singh and Hunter 2019). Another Pacific island state interested in hosting deep-sea mining operations within their jurisdiction is Tonga, which has already issued exploration licenses to several contractors under the country's mineral and petroleum mining law (Blue Ocean Law and the Pacific Network on Globalisation 2016; Singh and Hunter 2019). In 2014, Tonga has, however, adopted its new Seabed Minerals Act, which has been drafted with the help of the Secretariat of the Pacific Community and the European Union. Although the Seabed

Minerals Act contains suitable environmental provisions, including the requirement to submit environmental impact assessments (EIA), it is doubtful that the country will be able to implement and enforce the regulations, due to a profound lack of financial and institutional capacity (Singh and Hunter 2019). The Cook Islands are actively seeking contractors to exploit nodules within its EEZ. The country adopted its Seabed Minerals Act in 2009, which mainly aimed at facilitating mining and gave little attention to environmental concerns. The 2015 Seabed Minerals (Protection and Exploration) Regulations contained more provisions on the environment, albeit in weak language. The country has, however, implemented the Marae Moana Act in 2017, which establishes the marine protected area Marae Moana, including a 50km no-mine zone around the country's coastline (§24). In contrast to the small island states, New Zealand, which incorporated provisions on deep-sea mining in its 1991 Crown Minerals Act and 2012 Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act, appears to place greater emphasis on the protection of the environment and has even denied a mining application because of it (New Zealand EPA 2015; Singh and Hunter 2019).

4.3.2. The Area

The ISA has already issued three sets of prospecting and exploration regulations for nodules, crusts and SMS deposits and is currently in the process of developing a corresponding set of exploitation regulations. The draft application regulations contain requirements for the application for and approval of exploitation contracts, including the obligation to submit a plan of work, a mining plan, a feasibility report, a financing plan, a training plan, an emergency response and contingency plan, an environmental impact statement, an environmental management and monitoring plan, and a closure plan. The drafting process also included a stakeholder consultation phase, during which contractors identified gaps in the regulatory framework, including the lack of information on the operationalization of the polluter pays principle, the precautionary approach and the ecosystem approach, as well as the consideration of the impacts of climate change and cumulative effects. Furthermore, concerns were raised about the review of contractor compliance with environmental regulations and the unclarified relationship between environmental impact statements, environmental standards, and environmental management and monitoring plans. To this end, the contractors suggested the drafting of concrete guidelines for the preparation of environmental impact statements and environmental management, monitoring and closure plans, including the requirements for the collection of baseline data. The stakeholders, furthermore, called for the development of standards to ensure the protection of the marine environment (ISBA/26/C2). In addition to the exploration and exploitation guidelines, the ISA has issued the Recommendation for the Guidance of the Contractors for the Assessment of Possible Environmental Impacts Arising from Exploration for Marine Minerals in the Area (ISBA/19/LTC/8), which prescribes the collection of baseline data in the exploration areas employing best available technologies and to conduct environmental impact assessments before, during, and after the exploration activities. Although the recommendations are not legally binding, contractors are expected to follow them (Lodge 2015).

5. Economic Considerations

Whether deep-sea mining will yield net benefits and for whom, depends on numerous factors, including the occurrence, volume and composition of the mineral deposit to be mined, the capital and operational costs required for recovering them (especially in comparison to terrestrial mining), the development of the metal market, and whether the environmental costs of mining are considered (Jaeckel 2020; Folkersen et al. 2019; Mukhopadhyay et al. 2019; Van Nijen et al. 2019). Any predictions of the future profitability of deep-sea mining are complicated by persisting knowledge gaps, a high level of uncertainty, and the general difficulty of expressing environmental impacts in economic terms (Folkersen et al. 2019; Mukhopadhyay et al. 2019; Folkersen et al. 2018b). Where deep-sea mining is carried out in the Area, the profitability of deep-sea mining may also be influenced by the compensation of terrestrial-mining countries, which are negatively affected by metals obtained from deep-sea mining entering the global market, as demanded by the CHM (Christiansen et al. 2019). According to Van Nijen et al. (2019), this could likely occur with respect to the manganese market, which according to them is "shallow (low activity compared to the volume), non-transparent, and fragmented" (p. 579).

5.1. National Jurisdiction

Within national jurisdiction, states expect to benefit from hosting deep-sea mining operations in two ways: by receiving royalties from the contractors in exchange for the right to exploit the country's mineral resources, and by collecting corporate income tax (Mullins and Burns 2018). Particularly small island states appear to have high hopes to generate revenue for their economies by encouraging the development of a deep-sea mining industry. Although the economic benefits may be substantial given the countries low number of inhabitants, the income from deep-sea mining may in reality be limited, as royalties and tax rates will likely have to be set at a low level to incentivize mining (Mullins and Burns 2018; Cardno 2016). Furthermore, due to a lack of financial, technical and institutional capacity, the countries may undervalue the potential adverse environmental impacts associated with the exploitation of the resource, as well as any potential impacts on other economic sectors such as fishery and tourism (Christiansen et al. 2019). Moreover, asymmetric power relations, which occur when one partner is considerably stronger than the other and influences the terms of the contract in its favor, could further reduce the benefits for the host country. In the deep-sea mining context, this risk is particularly pronounced as many developing countries choose to enter into contracts with foreign mining companies and investors (Le Meur et al. 2018). This not only applies to areas within national jurisdiction but also to the Area, where several developing states act as sponsors for companies of their own nationality, but who are subsidiaries of large foreign corporations. Examples include Nauru Ocean Resources Inc., Tonga Offshore Mining Limited, and Marawa Research and Exploration Ltd., who are nationals of Nauru, Tonga, and Kiribati, respectively, but subsidiaries of the Canadian Company DeepGreen Minerals Inc.

If deep-sea mining is to take place, revenues generated by deep-sea mining will have to be carefully invested to ensure long-lasting benefits for the community. The development of an effective fiscal and revenue management framework prior to the commencement of mining is considered an essential pre-requisite in this regard (UNDP and UN Environment 2018). Such frameworks are recommended to include provisions on competitive procurement procedures, frequent independent audits of financial accounts, and the regular disclosure of non-commercial and non-confidential information to the public. Furthermore, transparency and the delineation of clear decision-making strategies are considered essential to minimize the risks of corruption and mismanagement of revenues (Sachs and Warner 1995; Ovesen et al. 2018).

An effective fiscal and revenue management regime can also limit the adverse impacts of asymmetric power relations (Le Meur et al. 2018). If managed poorly, the revenues obtained from mining may easily turn into a resource curse for the host countries, which has been frequently shown in the context of terrestrial mining. Particularly, developing countries which usually have less diversified economies, run the risk of becoming overly dependent on the extractive industry. In this case, countries become increasingly vulnerable to external economic shock caused by changes in commodity prices and production levels (Ovesen et al. 2018). Furthermore, they are prone to experience the Dutch disease, which describes a situation where economic growth in one sector, i.e., the extraction of a natural resource, leads to a decline in other sectors. The increased influx of foreign currencies as a consequence of the increased export of the resource may lead to the appreciation of the local currency, which may cause other sectors of the economy to become less competitive on the international market. The Dutch disease can be prevented or counteracted by developing clear budgetary plans, detailing in advance how and when revenues are to be invested in the short-, medium- and long-term (Soros 2007; Ovesen et al. 2018). Furthermore, the establishment of offshore wealth funds in foreign currencies outside the country has been identified as a measure to ensure economic security even after the revenues from deep-sea mining decline (Al-Hassan et al. 2013). If and how the Dutch disease may affect countries involved in deep-sea mining, has not yet been researched.

Particularly developing countries often lack the capacity to develop, implement and enforce effective legislative frameworks (Bradley and Swaddling 2018). This is critical, as structural and administrative weaknesses can lead to revenue losses and negatively affect the credibility of the framework among local and foreign investors (Ovesen et al. 2018). However, several organizations exist to assist governments with the development of fiscal and revenue management regimes, such as the Pacific Community (SPC) and the Pacific Financial Technical Assistance Center (PFTAC). The latter has, for example, aided the Cook Islands' Seabed Mineral Authority in developing a mining tax regime. Previously, the Commonwealth Secretariat Economic and Legal Section (ELS) had carried out a Seabed Minerals Fiscal Regime Analysis in 2012 and provided recommendations to the Cook Islands' government to consider in the preparation of its mining and fiscal regime to ensure consistency with international practice and stakeholder expectations. The Cook Islands' fiscal regime has recently been passed in parliament and will be administered by the islands' Ministry of Financial Economic Management (CI Seabed Minerals Authority 2019).

5.2. The Area

In the Area, the ISA is obligated by UNCLOS and the 1994 Agreement relating to the implementation of Part XI of UNCLOS (1994 IA) to develop a payment regime composed of a payment mechanism, which determines the financial contributions contractors have to make to the ISA in exchange for exploiting the resources of the Area (CHM), and a benefit-sharing mechanism, according to which the economic and non-economic benefits of deep-sea mining will be shared among all of the ISA's member states (UNCLOS, Article 140, (Van Nijen et al. 2019; Jaeckel 2020; Jaeckel et al. 2016). In developing the payment regime, the ISA has to follow six principles outlined in the 1994 IA, which demand that the payment mechanism must be "fair, non-discriminatory, simple, and within the range of payments prevailing for land-based mining" and contain a procedure for monitoring compliance (Jaeckel et al. 2016, p. 199). The process of the development of a payment mechanism is ongoing. Open question concern inter alia, the type and level of revenue raising charges to be contributed by the contractors and ways to account for the high risk of the contractors in developing emergent industry (Van Nijen et al. 2019). ISA consultants have suggested the implementation of a 2% ad valorem royalty during the early phase, which would later be increased to about 6% as the industry grows. In this case, about 70% of the proceedings would flow to the contractors, 2%–6% would be transferred to the ISA and the remainder would be paid as income tax to the country in which the contractor pays taxes (e.g., the sponsoring state) (The African Group 2018; Levin et al. 2020). The proposal by the ISA consultants has, however, been criticized by some of the ISA's member states, particularly by the African Group, which considers the revenue that would be raised by this scenario insufficient to compensate the ISA member states for the loss of resources in the Area (The African Group 2019; Levin et al. 2020).

Like the payment mechanism, the benefit-sharing mechanism is still being developed. However, neither UNCLOS nor the 1994 IA specify what the benefits of mankind entail and how they should be shared. This could, for example, include the direct re-distribution of the financial contributions from the contractors or the investment of their contributions into a fund (Christiansen et al. 2019). Given the current perspective on the level of royalties set by the ISA, it seems unlikely, however, that this will generate reasonable income for developing countries (The African Group 2018; Jaeckel 2020). The sharing of benefits could also include the provision of capacity-building opportunities and the sharing of scientific research findings. To this end, the ISA has, for example, initiated several training programs and issued several scholarships. Christiansen et al. (2019) point out that this could be improved through better organization and the establishment of "dedicated organs such as a school or university that systematically organizes education and capacity-building according to overarching educational goals" (p. 77). Furthermore, scientific data has, thus far, only been shared to a limited extent, although it has frequently been called for that particularly environmental data should be made available to the public (Seascape Consultants 2014; Jaeckel et al. 2016; ISBA/20/C/31 and ISBA/18/C/20).

6. Social Considerations

The potential social impacts of deep-sea mining have, thus far, received little attention in research. Their nature and magnitude, therefore, remain largely unknown.

Wherever deep-sea mining takes place in the vicinity of coastlines, concerns have been raised about potential direct and indirect impacts on fisheries and tourism (Koschinsky et al. 2018; Folkersen et al. 2018a; Roche and Bice 2013; Binney and Fleming 2016). In comparison to terrestrial mining operations, which often provide indirect employment opportunities through the development of settlements around mining operations, deep-sea mining will take place with little to no presence on land. Furthermore, deep-sea mining operations require highly skilled personnel with experience in the fields of offshore engineering, project management and shipboard services; it is, therefore, unlikely that many jobs will be filled by members of the local communities (Binney and Fleming 2016). Whether the inhabitants of coastal countries will benefit socially from deep-sea mining operation in their vicinity strongly depends on how their governments will choose to invest the revenues obtained from mining. If invested properly, the countries' additional income can contribute to the improvement of community and health services, infrastructure or affordable housing. Mismanagement and corruption, however, could negate any potentially positive impacts.

Whereas governments have generally responded positively to the prospects of hosting deep-sea mining operations in areas under their jurisdiction, local communities, as well as a number of national and international NGOs having assumed a more critical position (Koschinsky et al. 2018). This became particularly apparent in relation to the struggles of Nautilus Minerals, which are attributed in part to vehement community opposition. Although it has yet to be explored how people form their opinion of deep-sea mining (e.g., based on past experience with similar industries like terrestrial mining, on scientific facts or other factors), some insight could already be gained from the Nautilus Minerals case in Papua New Guinea. In relation to this project, Filer and Gabriel (2018) identified three different arguments frequently voiced by opponents to the Solwara 1 project. The first one emphasizes the application of the precautionary approach and, therefore, calls for an interruption of all mining-related activities until sufficient knowledge on its associated environmental impacts is available. The second argument is a religious or spiritual one, which portrays the ocean as a sacred space that must not be affected by mining. The third argument is of a legal nature and relates to the right of local communities of free, prior and informed (FPIC) consent, as stated in the United Nations Declaration on the Rights of Indigenous People. In the context of deep-sea mining, which will take place far offshore, it is, however, difficult to identify who would be entitled to FPIC (see Filer and Gabriel (2018) for a thorough assessment of this problem).

To increase the social sustainability of deep-sea mining operations, it is necessary to anticipate any potential social impacts prior to the commercialization of the activity. Important tools in this regard include social impact assessments (SIAs) (often included in EIAs) and the development of corresponding social impact management plans (SIMPs). Like their environmental counterparts, SIAs provide information about expected impacts to inform the decision-making of governments, stakeholders and the public, while SIMPs detail suitable response mechanisms. They further describe how potential positive impacts could be enhanced (Franks 2011; Franks and Vanclay 2013). Furthermore, more consideration should be given to FPIC and general stakeholder participation (see Singh and Hunter 2019 for an assessment of existing regulatory frameworks with respect to the incorporation of FPIC and stakeholder participation). Social impacts should, in any case, be a central component of deep-sea mining risk assessments.

7. Synthesis

7.1. Implications for Sustainable Development

Whether deep-sea mining can contribute to sustainability and sustainable development first and foremost depends on how sustainability is understood. In this regard, a distinction is commonly made between strong sustainability and weak sustainability. The concepts are closely linked to the five capitals theory, which assumes that there are different forms of capital: natural capital (e.g., natural resources, ecosystem services), financial capital (e.g., revenues), manufactured capital (e.g., goods, technology), human capital (e.g., work force, educational levels, skills of individuals), and social capital (e.g., norms, social networks, cooperation and trust) (Ang and van Passel 2012; Moldan et al. 2012). From a weak sustainability perspective, sustainability or sustainable development can be achieved by transforming one form of capital into another, as long as the overall stock of capital is maintained or increased. In contrast to this, proponents of the strong sustainability concept believe that the individual forms of capital need to be maintained in and of themselves. This is especially true for natural capital, as this is considered vital for the growth of the other forms of capital and, therefore, essentially irreplaceable by other forms of capital.

From a strong sustainability perspective, deep-sea mining would be inacceptable, as it not only describes the exploitation of a finite resource but will also be associated with substantial environmental impacts. From this perspective, the only viable option would be to reduce the demand for primary metals by increasing the rate of recycling, improving product design and increasing the longevity of products. This would also be in line with SDG 8, which calls for more sustainable consumption and production patterns. From a weak sustainability perspective, deep-sea mining could be considered sustainable if the conversion from natural capital (i.e., the resource in the ground and the in-tact ecosystem) into the other forms of capital (e.g., revenue, employment) would keep the overall level of capital constant. This requires a careful weighing of the benefits and costs of deep-sea mining.

By generating additional revenue for developing states through royalties and corporate income tax, deep-sea mining could theoretically contribute to achieving economic prosperity and human well-being, as, for example, called for by SDG 1 (ending poverty), SDG 2 (ending hunger), SDG 3 (health, well-being) and SDG 10 (reduce inequality within and among countries). Here, the CHM, which specifically requires the equitable sharing of the monetary and non-monetary benefits obtained from the exploitation of the marine mineral resources in the Area, is of particular importance (see also Christiansen et al. 2019). Furthermore, deep-sea mining can provide the metals required for producing the technology needed for the transition to a low-carbon economy. Crystalline photovoltaic panels, for example, contain substantial amounts of aluminum (Al), copper (Cu) and silver (Ag), as well as several other metals in smaller quantities. Wind turbines need significant quantities of iron (Fe), Cu, and Al. Electric vehicles typically use lithium-ion batteries to store electricity, which require metals like nickel (Ni), cobalt (Co), Al, and manganese (Mn) oxides, depending on the specific type of battery. In addition to this, electric vehicles and wind turbines often operate permanent magnet generators, which require significant quantities of rare earth elements (REEs), such as neodymium (Nd) and dysprosium (Dy) (Grandell et al. 2016). Many of these metals could likely eventually be extracted from marine mineral deposits. In this regard, deep-sea mining could contribute to achieving SDG 7 (sustainable and modern energy for all), specifically SDG 17.2 (by 2030, increase substantially the share of renewable energy in the global energy mix) and SDG 11 (make cities and human settlements, inclusive, safe, resilient and sustainable) if sustainable transport refers to electromobility (although this appears to be far-fetched). Following this line of reasoning, deep-sea mining could also indirectly contribute to achieving SDG 13 (take urgent action to combat climate change and its impacts).

However, deep-sea mining will entail the large scale and long-term destruction of the marine environment in and around the mine sites and cause inevitably the loss of biodiversity. In this regard, deep-sea mining stands in stark contrast to SDG 14 (sustainable life under water), specifically SDG 14.2 (sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans). The restoration of adversely affected deep-sea ecosystems is, however, particularly difficult and expensive. Furthermore, if ecosystem services, particularly the ability of the ocean and the seafloor to sequester carbon from the atmosphere, are compromised, deep-sea mining may also conflict with SDG 13 (combating climate change). Moreover, it is doubtful whether the revenues that could be generated by collecting royalties and income taxes (if paid to the host country), would be high enough to promote economic growth, improve social services and support institutions. Furthermore, mismanagement of revenues and the undervaluation of environmental impacts could cause the decline of other economic sectors, negatively affect the environment, and provoke social unrest. The latter may be the case particularly in developing countries which often lack the financial and institutional capacity to develop, implement and enforce sound regulatory frameworks.

7.2. Good Governance

If deep-sea mining cannot be prevented, it is important to reduce its adverse impacts as much as possible, for example, by implementing principles of good governance. The core characteristics of good governance include (1) rule of law, (2) accountability, (3) strategic vision, (4) responsiveness, (5) consensus orientation, (6) equity, and (7) effectiveness and efficiency (Kardos 2012). Although different institutions emphasize different elements, there is consensus that good governance is a crucial foundation of sustainable development. Ardron et al. (2018) have analyzed the role of transparency in the context of deep-sea mining in detail, which according to them, also relates to the elements of public participation and accountability. According to them, based on a thorough review of existing codes of conduct, regulations, international agreements, and voluntary standards, Ardron et al. (2018) identify six components of good practice in transparency and analyze to what extent the regulations and recommendations set forth by the ISA reflect these core aspects. They conclude that the ISA has been forward-thinking in some ways, for example, with respect to releasing information after a certain time period and the emphasis on the precautionary approach. Furthermore, they state that the draft exploitation regulations appear to indicate that transparency may be improving to a certain extent, for example, with respect to making exploitation contracts publicly accessible (although some have criticized that the ISA's effort is still not sufficient, see above). At the same time, the ISA's rules and regulations and procedures do not seem to reflect best practices. For instance, the application of the six components of transparency indicated weaknesses, such as the inaccessibility of annual reports, which are treated confidentially, unclear quality assurance, the lack of reporting on the compliance of states and contractors to ISA regulations, the lack of public participation as observers are not allowed to attend key committee meetings, and the limited possibility for civil society or state parties to request a review or appeal to decisions of the authority (Ardron et al. 2018).

Good governance also plays an important role, where developing countries are planning to host deep-sea mining operations in their EEZs or on their extended continental shelves. In these countries, the implementation and success of good governance principles is often limited by a lack of trained personnel capable of developing effective policy frameworks (e.g., fiscal and revenue management plans and environmental regulations), controlling the quality of impact assessments (e.g., EIAs and SIAs) and impact management plans (e.g., environmental management plans (EMPs), SIMPs), and monitoring compliance and enforcement. Capacity-building is, therefore, not only important with respect to minimizing the potential negative impacts of deep-sea mining, but also with respect to maximizing potential benefits of the activity. The Natural Resource Charter also provides guidance for "governments, societies and the international community", although their implementation may be challenging (Cust and Manley 2014, page 4).

Kung et al. (2020) highlight that "uncertainties are translating into defects in emergent [deep-sea mining] governance architecture", both within and beyond the limits of national jurisdiction (p. 8). They highlight in particular, that applying EIA methodology, albeit a well-established process, is difficult in the context of deep-sea mining, which is "a frontier industry with scant environmental data on the status quo, and with no functional precedent in in terms of project design" (ibid., p. 9). In contrast to terrestrial activities, which usually benefit from information of experiences made with similar processes in similar environmental settings, there is no such option for deep-sea mining. Furthermore, there is no definition yet of what actually constitutes serious harm. Experience from terrestrial mining can, however, be used, where conflicts of ownership or between users of the marine environment occur.

Independent of the decision for or against deep-sea mining, research on deep-sea ecosystems and potential environmental, economic and social impacts of deep-sea mining should be continued, as the past decades have shown that the interest in deep-sea mineral deposits may periodically reoccur and future generations should have a solid foundation of knowledge to make decisions based on scientific facts.

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